

*Studying Galaxy Evolution with Spitzer and Herschel*  
*CUP Conference Series, Vol. \*\*VOLUME\*\*, 2006*  
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## SED of starbursts

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**Abstract.** We provide a library of some 7000 SEDs for starbursts and ultra luminous galaxies (<http://www.eso.org/~rsiebenm/sb.models>). Its purpose is to quickly obtain estimates of the basic parameters, such as luminosity, size and dust or gas mass and to predict the flux at yet unobserved wavelengths. The procedure is simple and consists of finding an element in the library that matches the observations. The objects may be in the local universe or at high  $z$ . We calculate the radiative transfer in spherical symmetry for a stellar cluster permeated by an interstellar medium with standard (Milky Way) dust properties. The cluster contains two stellar populations: old bulge stars and OB stars. Because the latter are young, a certain fraction of them will be embedded in compact clouds which constitute hot spots that determine the MIR fluxes. We present SEDs for a broad range of luminosities, sizes and obscurations. We argue that the assumption of spherical symmetry and the neglect of clumpiness of the medium are not severe shortcomings for computing the dust emission. The validity of the approach is demonstrated by matching the SED of the best studied galaxies, including M82 and Arp220, by library elements; one example is shown for a galaxy at high redshift ( $z \sim 3$ ). Generally, one finds an element which fits the observed SED very well, and the parameters defining the element are in full accord with what is known about the galaxy from detailed studies.

**Introduction:** By definition, the rapid conversion of a large amount of gas into predominantly massive ( $> 8M_{\odot}$ ) stars, or the result of such a conversion, is called a starburst. Starburst galaxies constitute a unique class of extragalactic objects. The phenomenon is of fundamental importance to the state and evolution of the universe (Heckman 1998). Starbursts are also cosmologically significant if one interprets the high bolometric luminosities of high redshift galaxies to be due to star formation (Chary & Elbaz 2001). To interpret infrared observations and to arrive at a self-consistent picture for the spatial distribution of stars and interstellar matter in the starburst nucleus and of the range of dust temperatures, one has to simulate the transfer of continuum radiation in a dusty medium (e.g. Krügel & Siebenmorgen 1994). Line emission is energetically negligible.

A starburst has four basic parameters: total luminosity,  $L$ , dust or gas mass,  $M_d$  or  $M_{\text{gas}}$ , visual extinction,  $A_V$ , and size. Size,  $A_V$  and  $M_d$  are, of course, related, for a homogeneous density model, only two of them are independent. The luminosity follows observationally in a straight forward way by integrating the spectral energy distribution over frequency,  $M_d$  is readily derived from submillimeter data, and the outcome is almost independent of the internal structure or viewing angle of the starburst. The size is best obtained from radio observations.

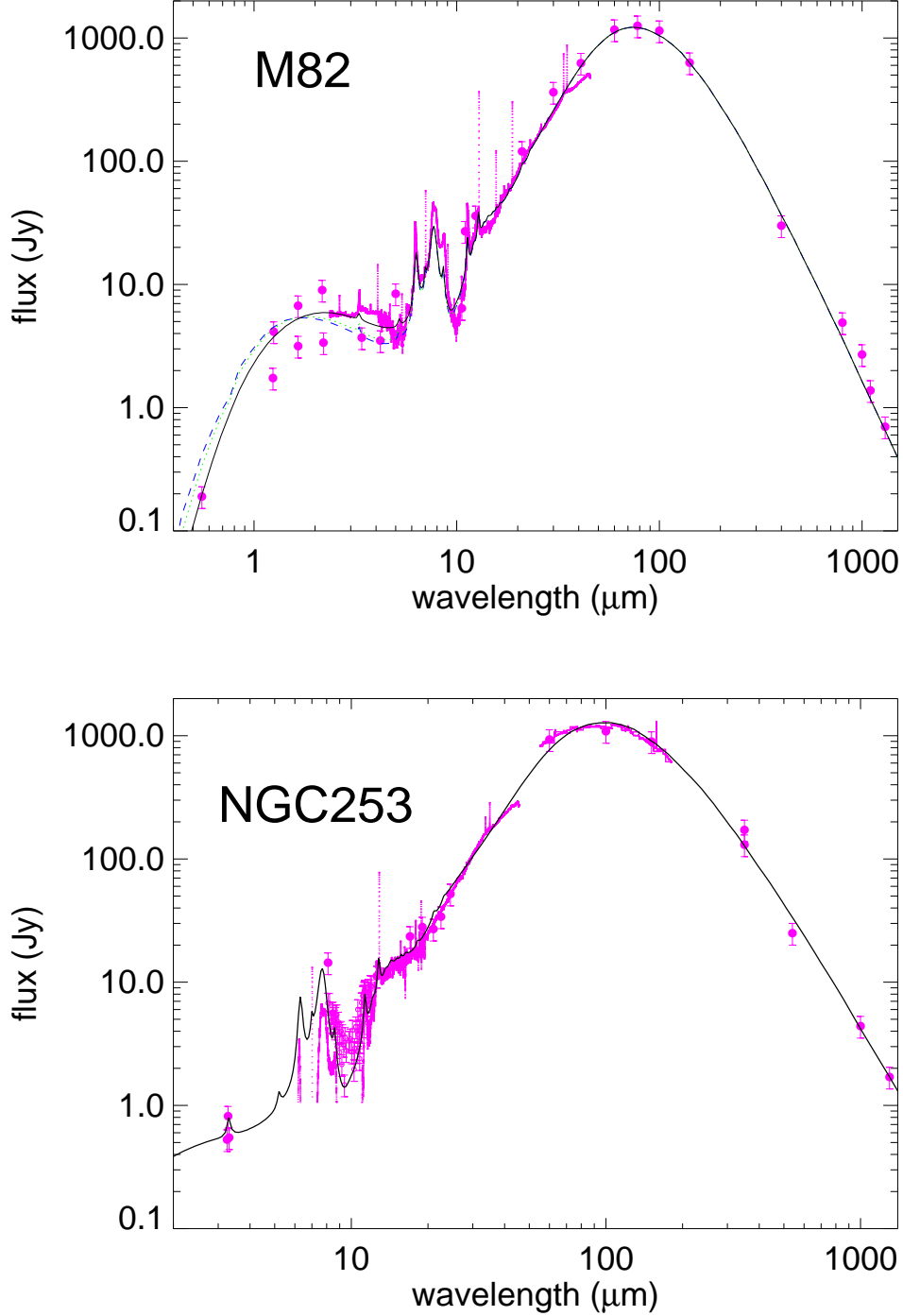


Figure 1. SED of the central region of M82 (*top*) and NGC253 (*bottom*). Data points with  $1\sigma$  error bar as available in NED, ISO, IRAS; NIR photometry in  $40'' - 100''$  aperture. Full line: library model with parameters for M82 ( $L^{\text{tot}} = 10^{10.5} L_{\odot}$ ,  $D = 3.5\text{Mpc}$ ,  $R = 350\text{pc}$ ,  $A_V = 36\text{mag}$ ,  $L_{\text{OB}}/L^{\text{tot}} = 0.4$ ,  $n^{\text{hs}} = 10^4\text{cm}^{-3}$ ) and NGC253 ( $L^{\text{tot}} = 10^{10.1} L_{\odot}$ ,  $D = 2.5\text{Mpc}$ ,  $R = 350\text{pc}$ ,  $A_V = 72\text{mag}$ ,  $L_{\text{OB}}/L^{\text{tot}} = 0.4$ ,  $n^{\text{hs}} = 7500\text{cm}^{-3}$ ). For M82 to fit data below  $5\mu\text{m}$ , we added to the SED library spectrum a blackbody, either unreddened ( $T = 2500\text{K}$ , full line), or reddened ( $T = 8000\text{K}$ ,  $A_V = 4\text{mag}$ , dashed, or  $T = 5000\text{K}$ ,  $A_V = 3\text{mag}$ , dotted).

**Model description:** We use standard dust. It consists of large silicate and amorphous carbon grains with a size distribution. A population of small graphite grains ( $< 100\text{\AA}$ ) and two kinds of polycyclic aromatic hydrocarbons (PAH). Our dust mixture produces reddening in rough agreement with the standard interstellar extinction curve for  $R_V = 3.1$ . An important feature of our radiative transfer model is the division of the sources in the starburst nucleus into two classes. *a)* OB stars in dense clouds with total luminosity  $L_{\text{OB}}$ . The immediate surroundings of such a star constitutes a *hot spot* which determine the MIR part of the SED of the nucleus. *b)* The total luminosity of all other stars is  $L_{\text{tot}} - L_{\text{OB}}$ . They are not enveloped in a dense cloud. For detailed description see Siebenmorgen & Krügel (2006). In the following we give three examples.

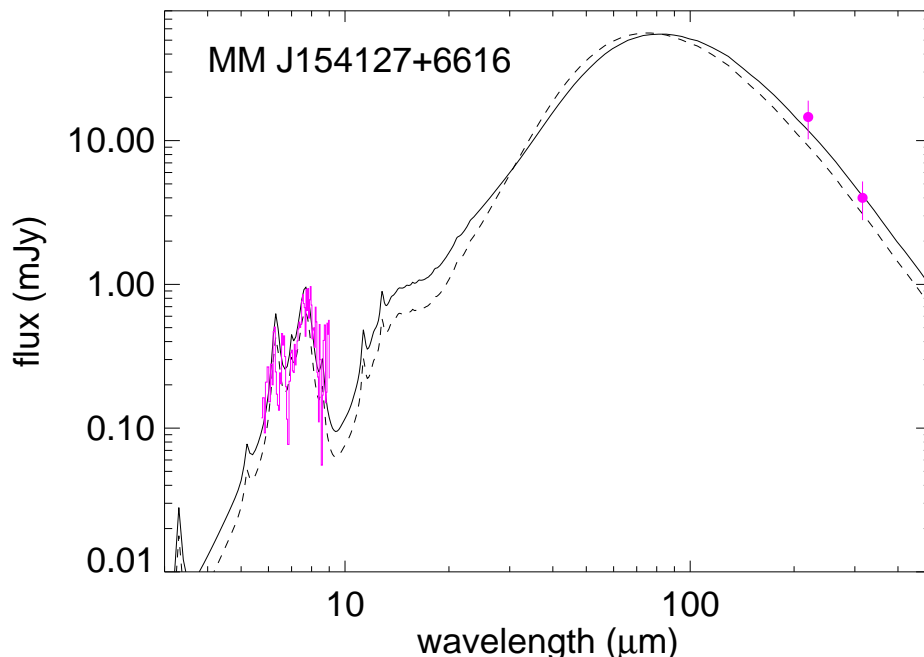


Figure 2. The spectrum of MMJ154127+6616 in the restframe of the galaxy ( $z = 2.8$ ) with two library models. Model parameters: *solid line*:  $L = 10^{13.7} L_{\odot}$ ,  $A_V = 70$  mag,  $R = 15$  kpc; *dashed line*:  $L = 10^{13.7} L_{\odot}$ ,  $A_V = 120$  mag,  $R = 9$  kpc. Observational points from Lutz et al. (2005), Eales et al. (2003) and Bertoldi et al. (2000).

**M82:** The present model for this archetype starburst is similar to the one proposed before (Krügel & Siebenmorgen 1994). At shorter wavelengths, the observed flux does not steeply decline, as one would expect judging from the depth of the silicate absorption feature ( $A_V \geq 15$  mag). Therefore, either hard radiation leaks out because of clumps or funnels created by supernova explosions, or there are stars in M82 outside the opaque nuclear dust clouds. As our model cannot handle clumping, but we nevertheless wish to extend the spectrum into the UV, we simply add another stellar component, which is not included

in a self-consistent way, but as its luminosity is  $\sim 10\%$  of the total, such an approximation may be tolerable. The stellar temperature and foreground reddening of the additional component are poorly constrained (Fig.1). This is also reflected by the controversial interpretations via an old stellar population (Silva et al. 1998) or via young, but obscured stars (Efsthathiou et al. 2000).

**NGC253:** shows at high resolution in the MIR a complex structure. Nevertheless, the low spatial resolution observations are well reproduced in our fit (Fig.1). Below 2 Jy, ISOSWS data are noisy and have therefore been omitted. The dip at  $18\mu\text{m}$  in the model of Piovan et al. (2006) is not present in ours, and not borne out by the observations.

**High redshift galaxies:** The library also seems to be applicable to extremely luminous objects at large redshifts. We demonstrate this in Fig.2 for the sub-millimeter galaxy MMJ154127+6616 which is at  $z = 2.8$  as derived from the identification of PAH features in the Spitzer IRS low resolution spectrum (Lutz et al., 2005). It seems to be an extremely massive object ( $10^{11} M_{\odot}$ ) where the starburst comprises the whole galaxy. For luminosities above  $10^{12.7} L_{\odot}$ , we have therefore modified the structure of the models accordingly. *a)* The size is increased to  $R = 9$  kpc and 15 kpc. *b)* There are only OB stars as giants have had no time to evolve. 40% of the stars are assumed to be in regions of enhanced density (hot spots). *c)* The star formation region extends to the edge of the galaxy. One finds two entries in the library which are compatible with the observations (Fig.2), both imply extreme luminosities ( $L_{\text{dust}} = 10^{13.7} L_{\odot}$ ) and dust masses close to  $10^{10} M_{\odot}$ .

**Conclusion:** A set of spectral energy distributions for starbursts covering a wide range of parameters is presented by Siebenmorgen & Krügel (2006). Anyone with infrared data and interested in their interpretation can compare them with our models, find an SED that matches (after normalization of the distance) and thus constrain the properties of the starburst under investigation without having to perform a radiative transfer computation himself.

**Acknowledgements:** We thank D. Lutz for providing the observed SED of MM J154127+6616.

## References

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